



# *Dark Energy Survey Supernovae*

## *Simulations and Survey Strategy*

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43<sup>rd</sup> Rencontres de Moriond, La Thuile, Italy, 20 March 2008

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# Outline

- Introduction
- Light curve simulator & fitter
- Bias studies
- Survey figure of merit
- Summary & conclusions

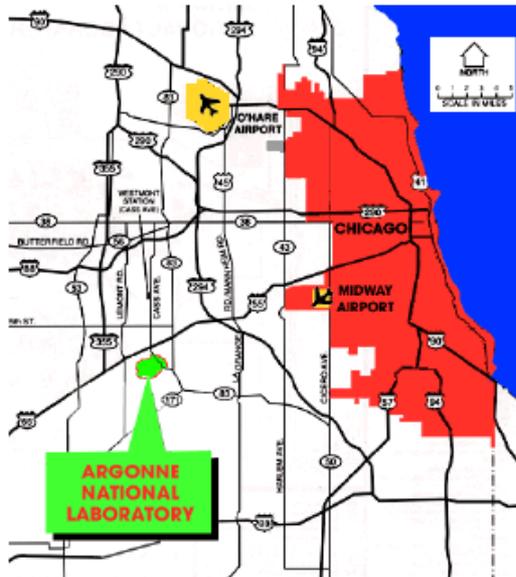


DARK ENERGY  
SURVEY



University of Chicago

# Argonne National Laboratory



- Argonne research areas (broadly)
    - basic science
    - applied science
    - energy resources
    - leadership computing. . .
  - High energy physics & astrophysics included
  - New astrophysics initiative
    - \$2M USD lab funding FY 2008
    - ramping up astrophysics activities
    - active search to attract a scientific leader who can establish & shape this initiative
- Contact: Karen Byrum, [byrum@hep.anl.gov](mailto:byrum@hep.anl.gov)

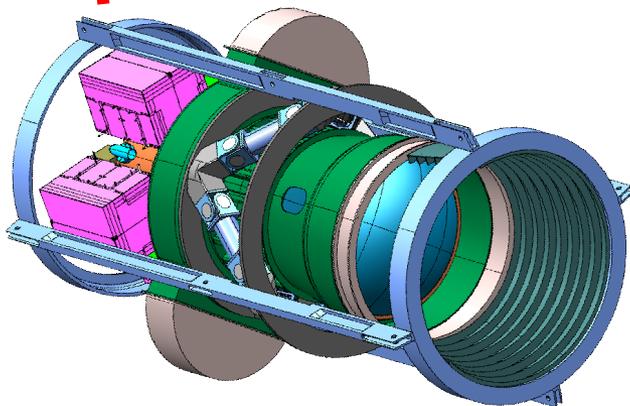
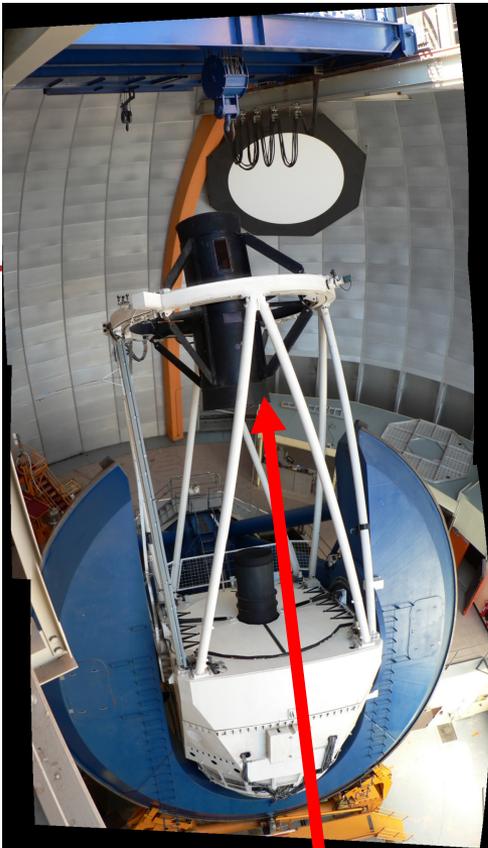


Image courtesy ipl.org

# Dark Energy Survey (DES)

DES is providing a new 520Mpixel CCD camera (DECAM) for the Blanco 4m telescope in Chile in exchange for 525 survey nights over 5 year period

DES group at Argonne:  
Joe Bernstein, Steve Kuhlmann, Hal Spinka,  
& Rich Talaga, plus Vic Guarino & Allen Zhao



# Dark Energy Survey (DES) Supernovae

- DES time allocation fixes total supernovae (SNe) exposure time
  - 1000 hr planned over 5-year survey period
  - maximal use of non-photometric time (~500 hr) planned
- Time per field & number of fields can be simulation optimized
  - Ultra-deep strategy (3 square degrees = 1 DES field)
  - Deep strategy (9 square degrees)\*
  - Shallow but wide strategy (27 square degrees)
  - or a hybrid approach
- Total DES survey is 5000 square degrees

\* Highlighted in DES DOE proposal.

# Current Favored DES *Supernova* Fields

■ Chosen to maximize:

- visibility from DES site
- past observation history
- visibility from, e.g, Hawaii

Chandra Deep Field – South ●

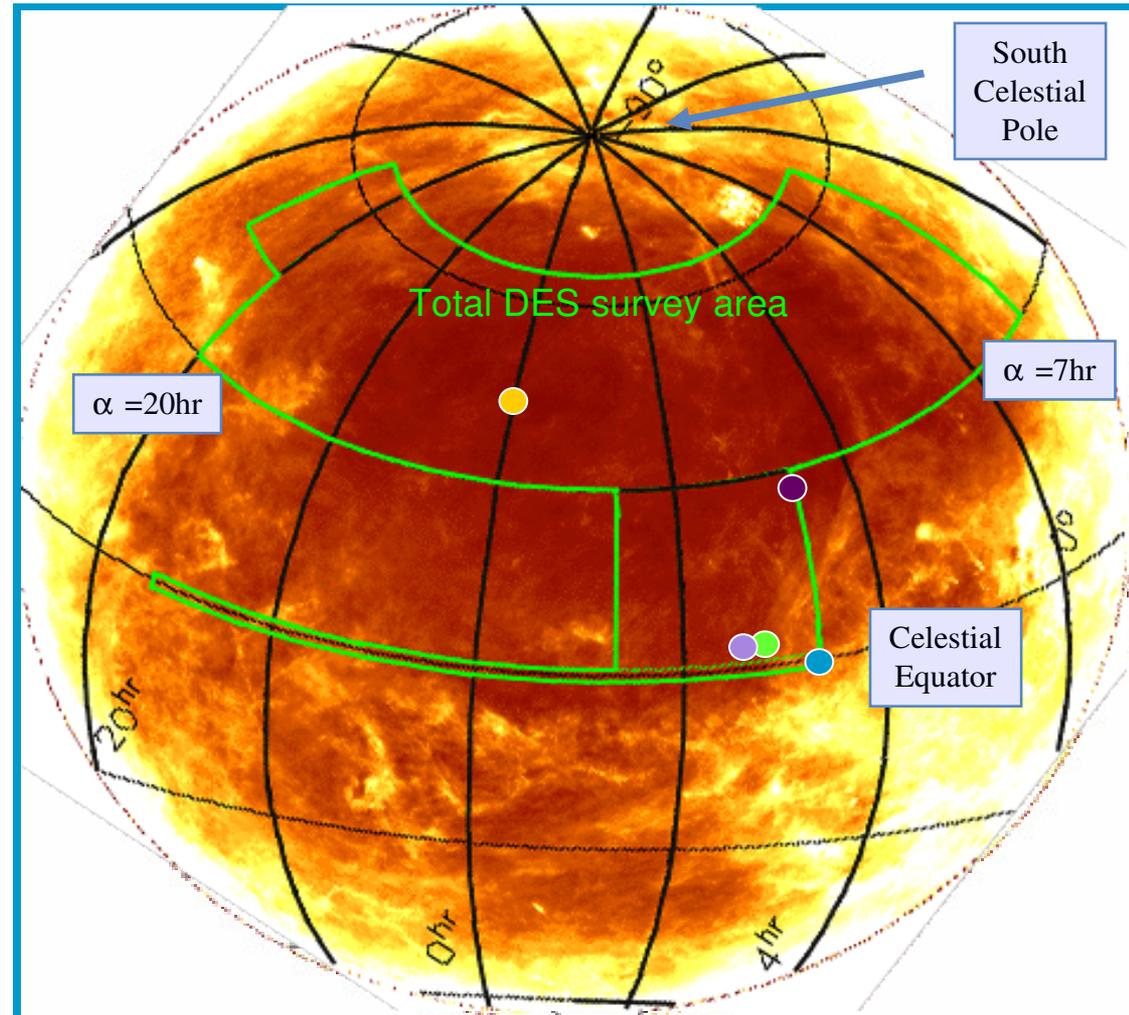
Sloan Stripe 82 ●

SN Legacy Survey (SNLS) D1 ●

XMM-Newton LSS ●

ELAIS S1 ●

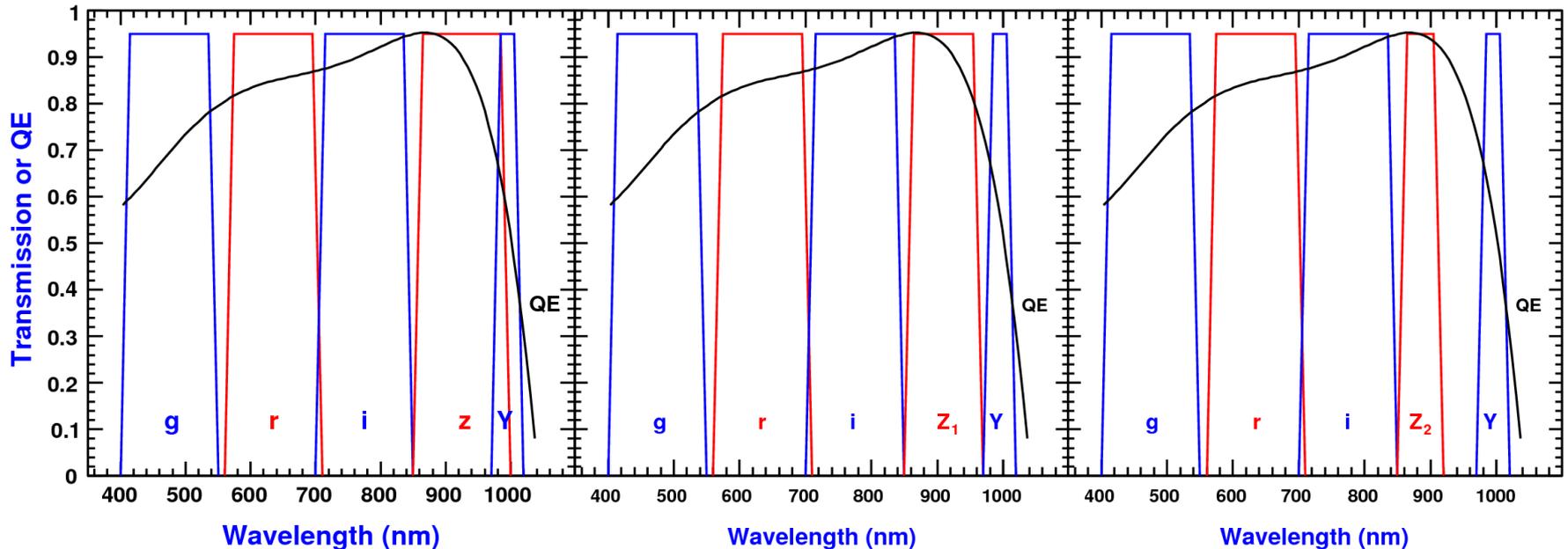
From a study by Peter Nugent



# Spectroscopic Strategy

- Spectroscopy of full SNe sample?
  - expensive (large-telescope observing time)
  - plan is follow-up for ~25% of SN sample
- Full host galaxy follow-up more feasible
  - negligible redshift errors ( $\Delta z < 0.001$ )
  - redshift critical for distinguishing type Ia & II SNe

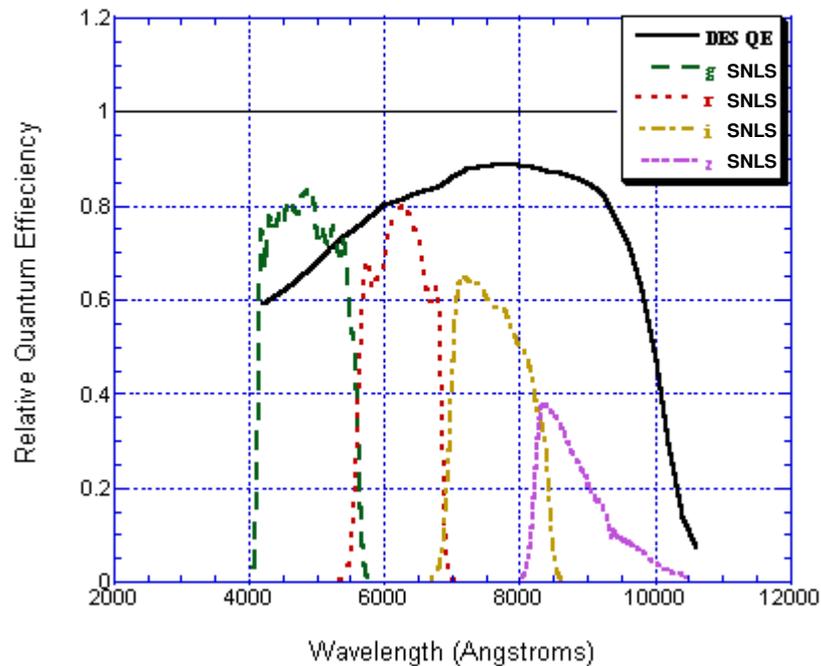
# DES Filters



■ Filters: g, r, i, z or Z<sub>1</sub> or Z<sub>2</sub>, Y ?

- Deep exposure times ~300s, 600s, 1800s, 1667s, 2333s in g, r, i, z, Y ?
- longer/shorter for ultra-deep/wide surveys (total time fixed)
- cadence: 6-8 days worst case, 3-4 days typical?

# DES vs. SNLS: Quantum Efficiency



Plot courtesy of John Marriner

The DES uses thicker LBNL CCDs with increased sensitivity at redder wavelengths

# SNANA Software Package for DES

R. Kessler (U. Chicago), J. P. Bernstein, S. Kuhlmann, & H. Spinka (ANL)

- Software suite for simulating and fitting SN light curves
- Publicly available: [http://www.hep.anl.gov/des/snana\\_package](http://www.hep.anl.gov/des/snana_package)
- Goal: an accurate and complete study of DES Supernovae capabilities including DES CCD & filter characteristics, Cerro Tololo Inter-American Observatory (CTIO) sky fluctuations using data inputs from the ESSENCE SN survey, dust extinction effects, etc.
- Also used by other projects
  - Sloan Digital Sky Survey (SDSS)
  - Large Synoptic Survey Telescope (LSST) SN project

# Simulator Description

- Computes rest-frame model magnitudes using various models
- Applies random color/luminosity fluctuations
- Includes host galaxy dust extinction
- Applies K-corrections
- Offers a choice of cosmologies
- Applies Milky Way dust extinction via Schlegel maps\*
- Uses survey zero-points to convert magnitudes to flux
- CCD gain, noise, and sky noise added

Fitter included for resulting light curves

# Multi-color Light Curve Shape Model

(MLCS2k2; Jha, Riess, Kirshner 2007, ApJ, 659, 122)

- Light curve model magnitude  $m_x$  for passband  $x$  at given epoch:

$$m_x = M_x + \mu_0 + \Xi_{x,MW} + \Xi_{x,H}(R_v, A_{v0}) + P_x \Delta + Q_x \Delta^2$$

- 4 free parameters:

- $t_0$ : epoch of maximum light in B-band
- $\mu_0$ : distance modulus
- $\Delta$ : luminosity/light curve shape parameter
- $A_{v0}$ : extinction in magnitudes by host dust;  $R_v = A_{v0} / E(B-V)$ , initially set to 3.1\*

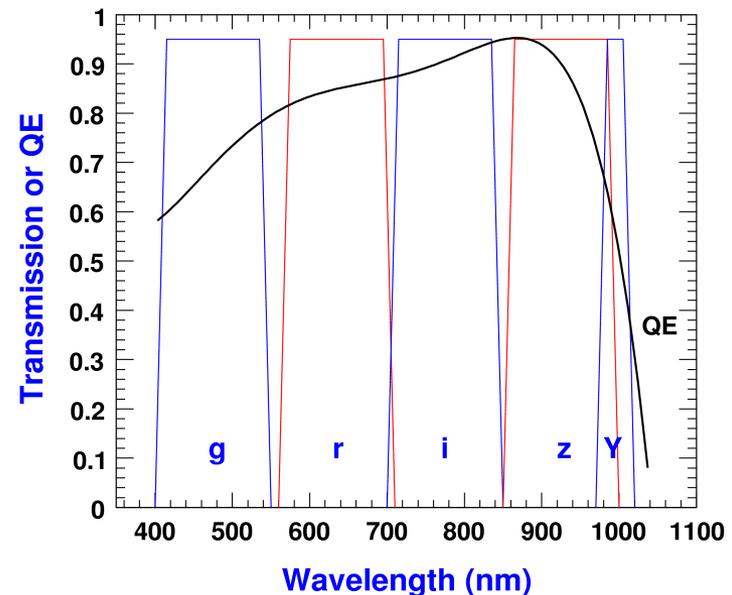
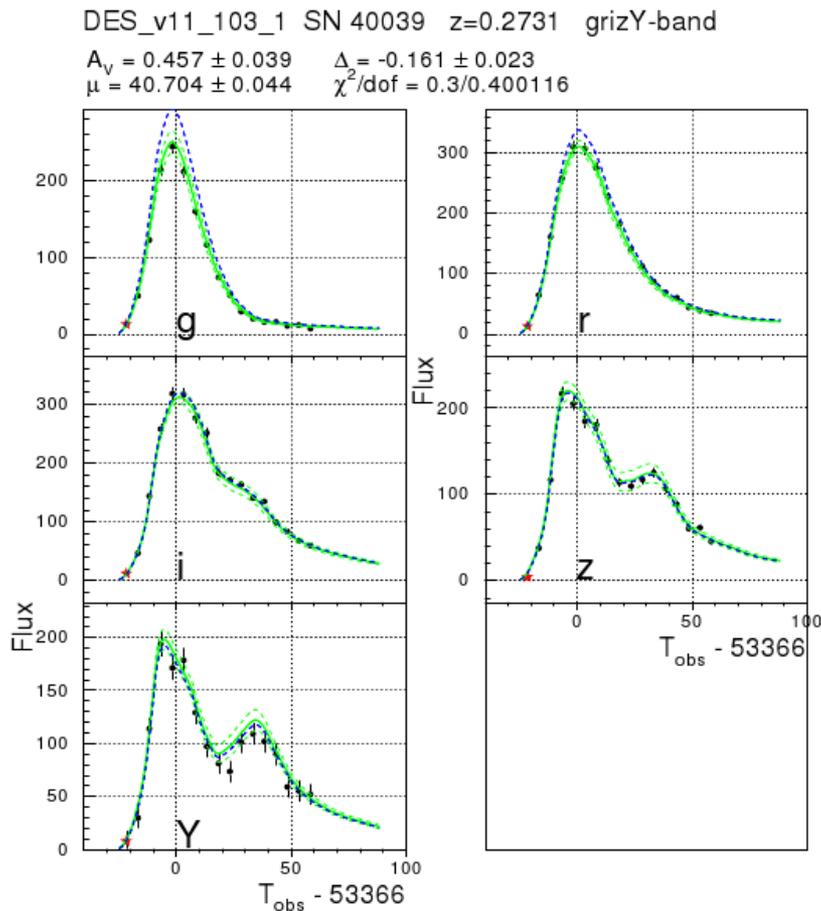
- Provided by MLCS2k2 SN data training (Jha,Riess,Kershner 2007):

- $M_x$ : rest-frame magnitude w/  $\Delta = A_{v0} = 0$
- $P_x$  &  $Q_x$ : describe change in shape & luminosity as function of  $\Delta$
- $\Xi_x$ : extinction functions; “MW” for Milky Way & “H” for host galaxy

\* Cardelli, Clayton, Mathis 1989, ApJ, 345, 245, and references therein

# Simulated DES Light Curves

Example light curve at  $z \sim 0.27$  for a deep survey (9 sq. deg.) using the grizY filter set. 2nd bump unique to SN type Ia.

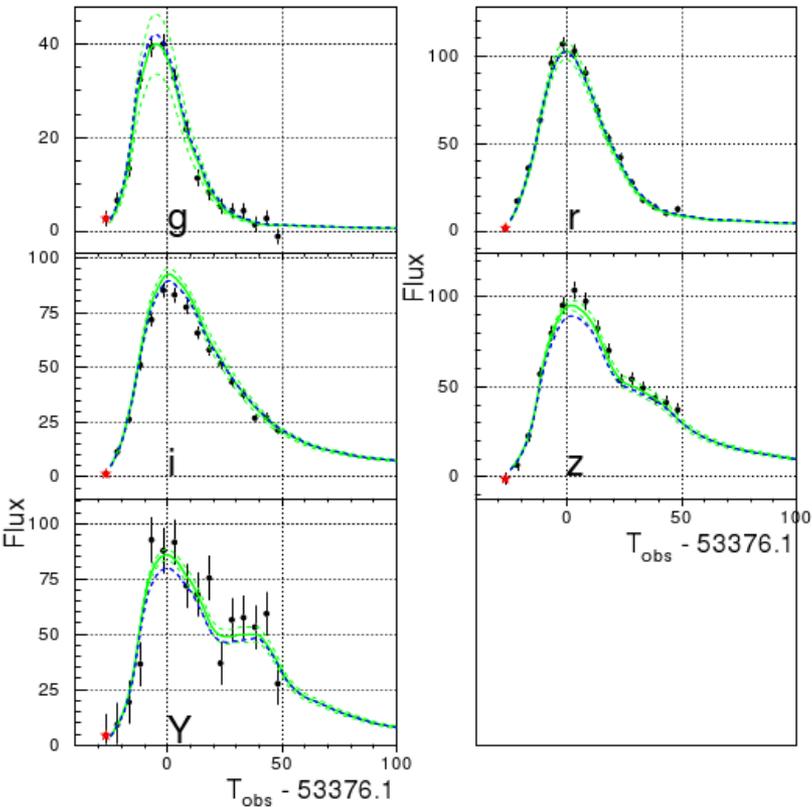




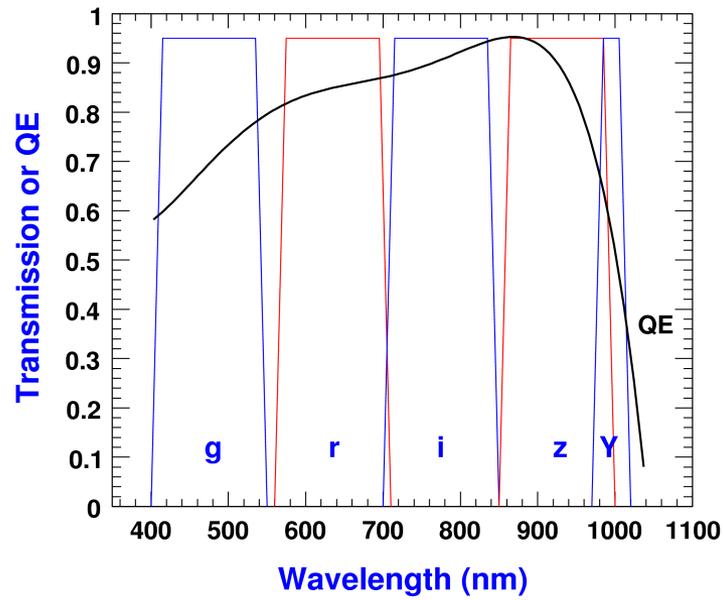
# DES Light Curves

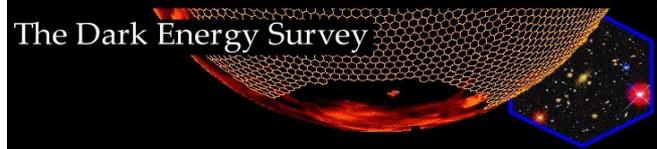
DES\_v11\_103\_1 SN 40016 z=0.4926 grizY-band

$A_V = 0.42 \pm 0.057$     $\Delta = -0.109 \pm 0.036$   
 $\mu = 42.192 \pm 0.066$     $\chi^2/\text{dof} = 0.3/0.379765$



Example light curve at  $z \sim 0.49$  for a deep survey (9 sq. deg.) using the grizY filter set.

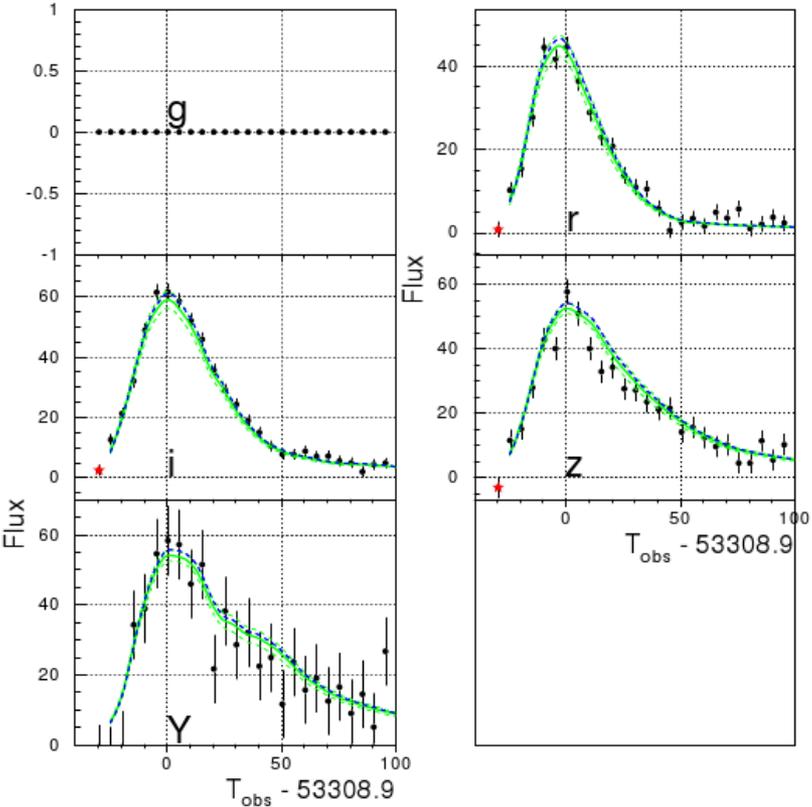




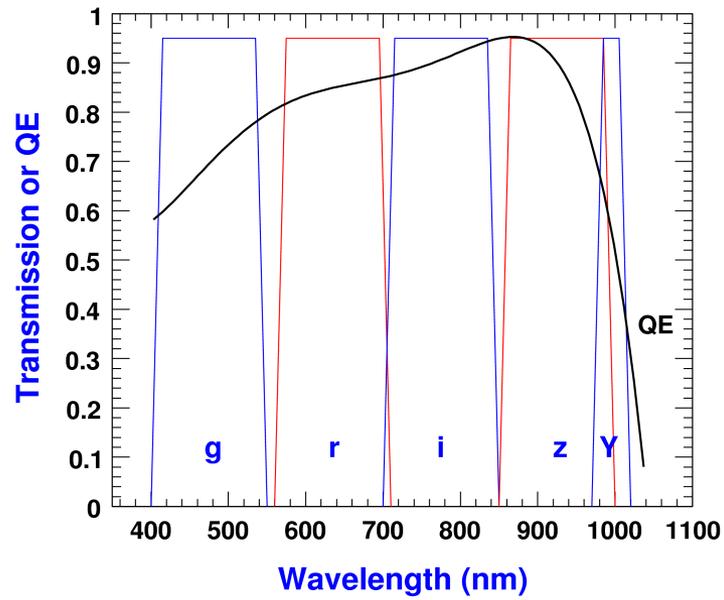
# DES Light Curves

DES\_v11\_103\_1 SN 40027 z=0.7467 grizY-band

$A_V = 0.028 \pm 0.029$      $\Delta = -0.245 \pm 0.038$   
 $\mu = 43.525 \pm 0.051$      $\chi^2/\text{dof} = -0.1/-0.215728$



Example light curve at  $z \sim 0.75$  for a deep survey (9 sq. deg.) using the grizY filter set.

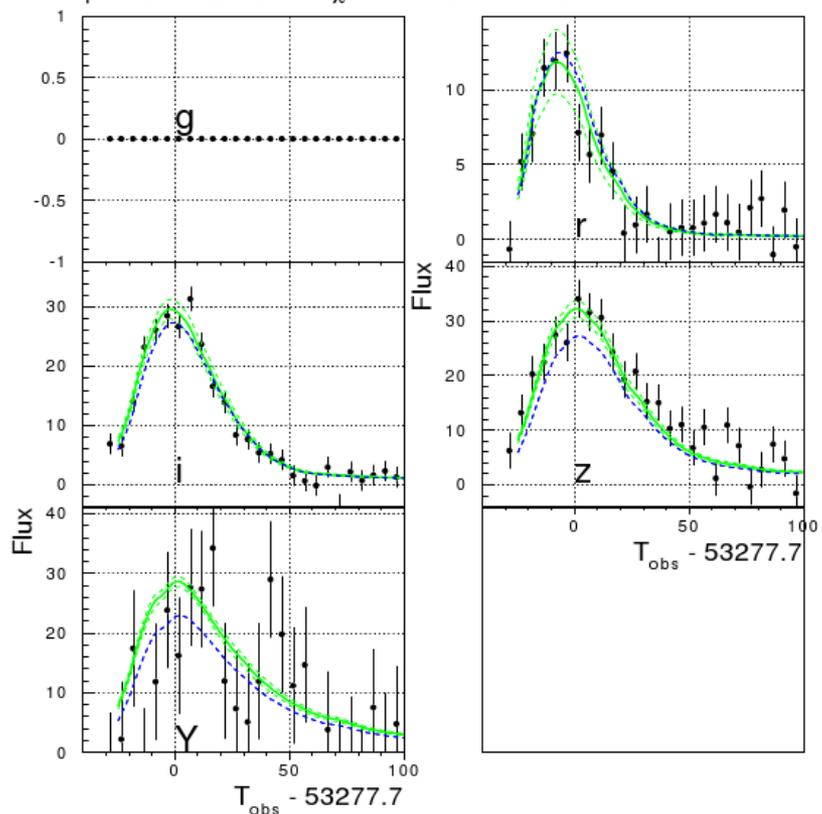




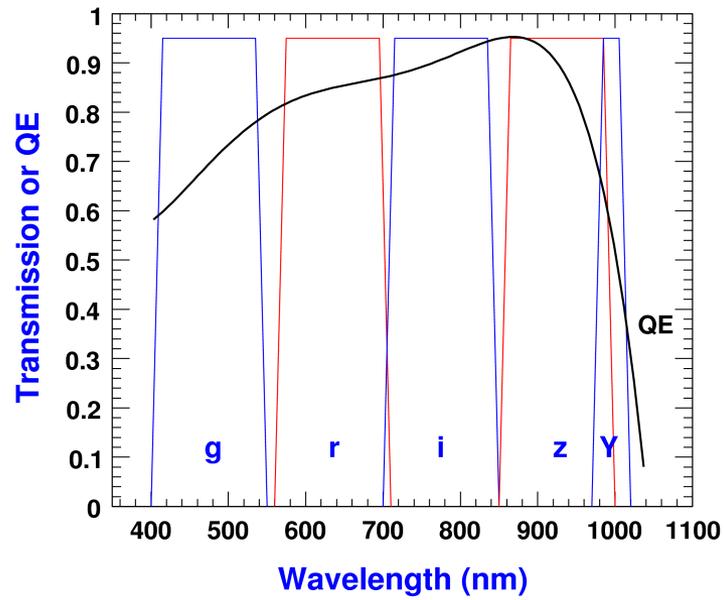
# DES Light Curves

DES\_v11\_103\_1 SN 40138 z=1.0154 grizY-band

$A_V = 0.59 \pm 0.206$   $\Delta = -0.117 \pm 0.058$   
 $\mu = 43.511 \pm 0.281$   $\chi^2/\text{dof} = 0.5/0.601442$

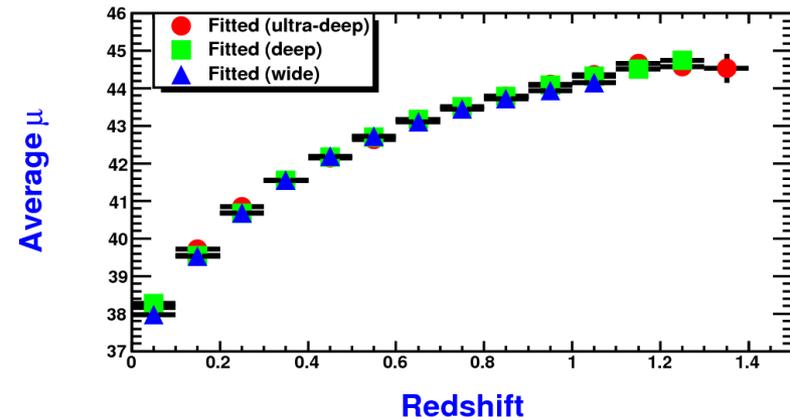
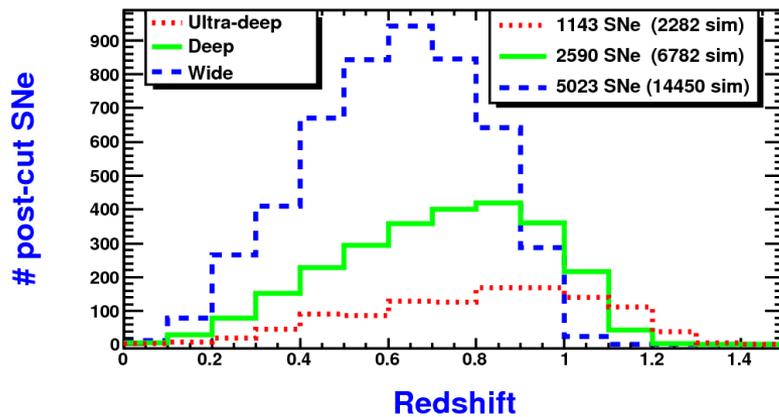


Example light curve at z~1.0 for a deep survey (9 sq. deg.) using the grizY filter set.

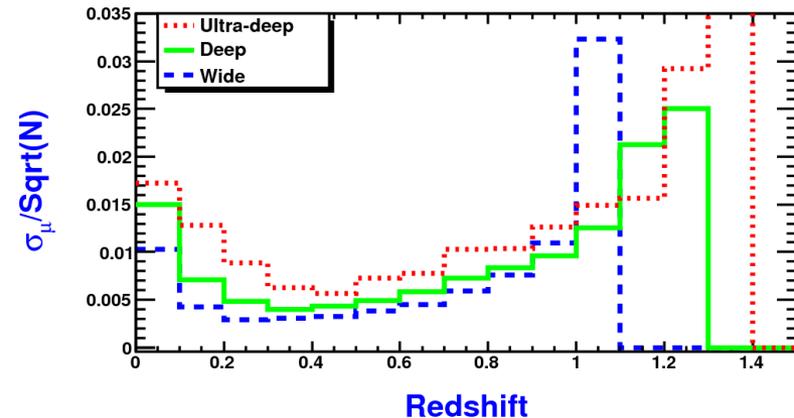


# Number of SNe & Statistical Distance Error

Cuts of 1 filter > 10 and any 3 > 5 S/N have been applied for the grizY filter set

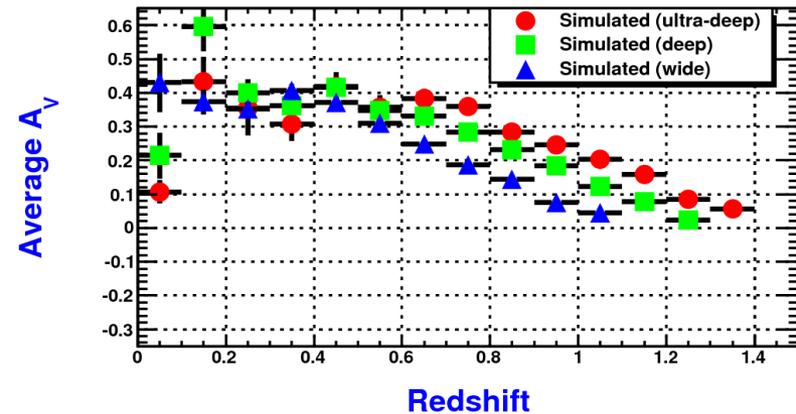
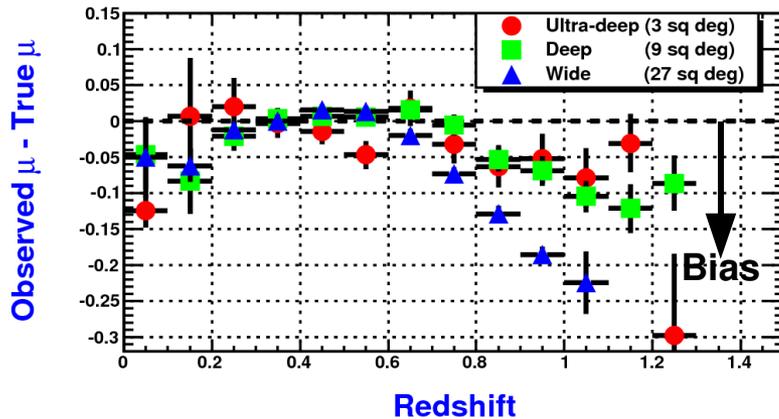


Error on the Hubble diagram for ultra-deep, deep, & wide surveys (3, 9, 27 sq. deg., respectively)

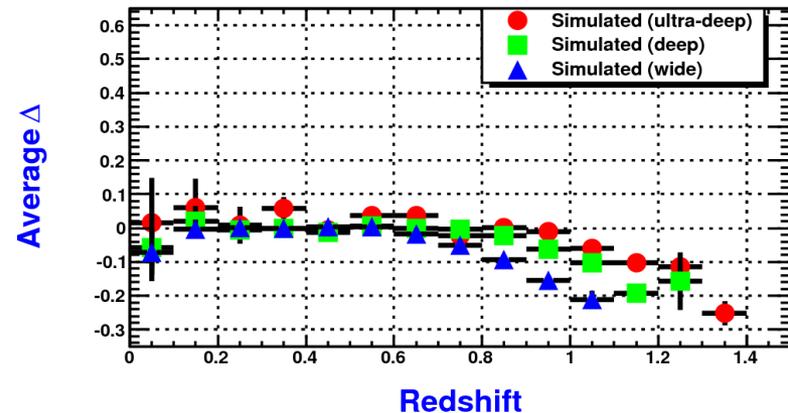


# Sensitivity of $\mu$ to Extinction Priors

Cuts of 1 filter  $> 10$  and any 3  $> 5$  S/N have been applied for the grizY filter set

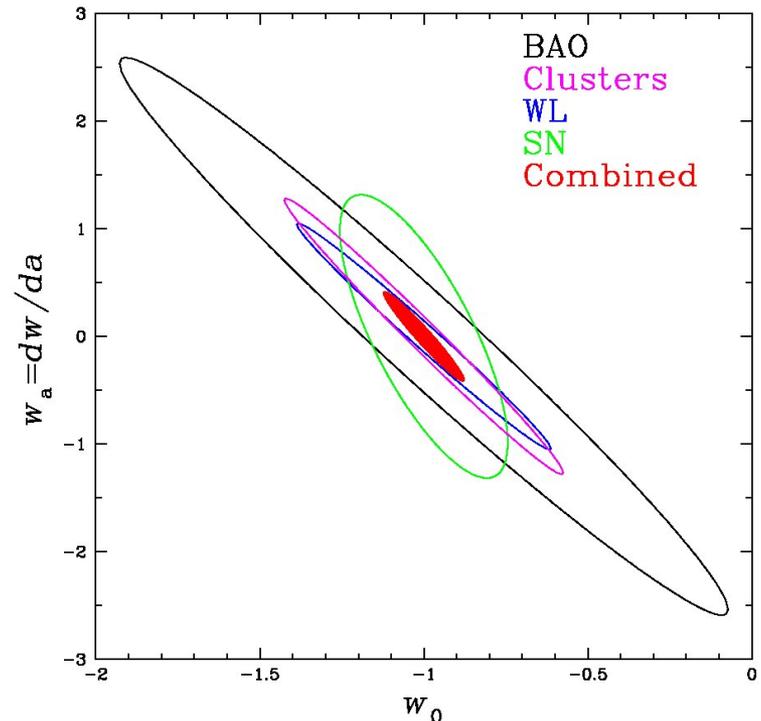


A bias in  $\mu$  is evident in the difference in the fitted and simulated values, arises from selection efficiencies not being taken into account, and illustrates the magnitude of the  $\mu$ -correction that will be needed



# DES Figure of Merit (FoM)

- Dark Energy Task Force (DETF) FoM: inverse size of  $w_a - w_o$  error ellipse
  - $w(a) = w_o + (1-a)w_a$
  - $a$  = scale factor
  - $w_o = w$  at present epoch
  - $w_a =$  rate of change of  $w$  with  $a$
- Systematic effects to consider:
  - light curve model
  - dust extinction vs. intrinsic color
  - photometric calibration
  - non-1a background
- DES survey strategy emphasizes best FoM + control of above systematics



Four DES methods to constrain dark energy (plot from NSF/DOE proposal including Planck priors but NOT the DETF Stage II constraints)

# DES FoM

Method	$[\sigma(w_a) \sigma(w_p)]^{-1}$
BAO	72.8
Clusters	152.4
Weak lensing	155.8
Supernovae	107.5
Combined DES	263.7
DETF Stage II combined	57.9

**Projection** from NSF/DOE proposal

N.B.:  $w_p = w(a_p)$  where  $a_p$  minimizes the error in  $w$  for given model. The area of the error ellipse in the  $w_p - w_a$  plane equals the area in the  $w_0 - w_a$  plane  $\Rightarrow$   
 DETF FoM  $\propto [\sigma(w_a) \sigma(w_p)]^{-1}$   
 (DEFT Final Report, 2006)

**DES offers an improvement on the DETF Stage II constraints by factor of 4.6**

Currently working on using a cosmology fitter to calculate simulated FoM from SNANA light-curve fits

# Summary & Conclusions

- DES simulates SN light curves via realistic SNANA package
- Light curves harnessed to study effects of:
  - survey depth (ultra-deep vs. deep vs. wide)
  - choice of filter sets & exposure times
  - cadence including weather
  - magnitude of a selection bias
  - color systematics including fitting  $A_V/R_V$  instead of fixing  $R_V$
- With FoM simulation  $\Rightarrow$  constraint on optimal survey strategy
- Ultimately: strategy whitepaper & (possibly) bias studies paper



# Additional Slides

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# DES Zeropoint/Sky Estimates: grizY

(mag =  $-2.5 \cdot \text{LOG}(\text{Flux in ADU}) + \text{Zeropt}$ ) (1 ADU = 1 e-) (1 arcsec  $\rightarrow$  30.1 Npixels)

	e-/100s for 20th mag	Zeropt for 100s, 100s, 200s, 200s, 200s	SQRT(SKY) for 100s, 100s, 200s, 200s, 200s	Our Limiting Magnitude for 10 sigma for 100s, 100s, 200s, 200s, 200s	Table 8 Vista Proposal (Limiting Mag for 10 sigma)
g	49800	31.7	149	23.8	23.8
r	49400	31.7	236	23.3	23.3
i	36940	32.2	400	23.2	23.3
z	38000	32.2	735	22.5	22.6
Y	7600	30.5	520	21.2	21.2

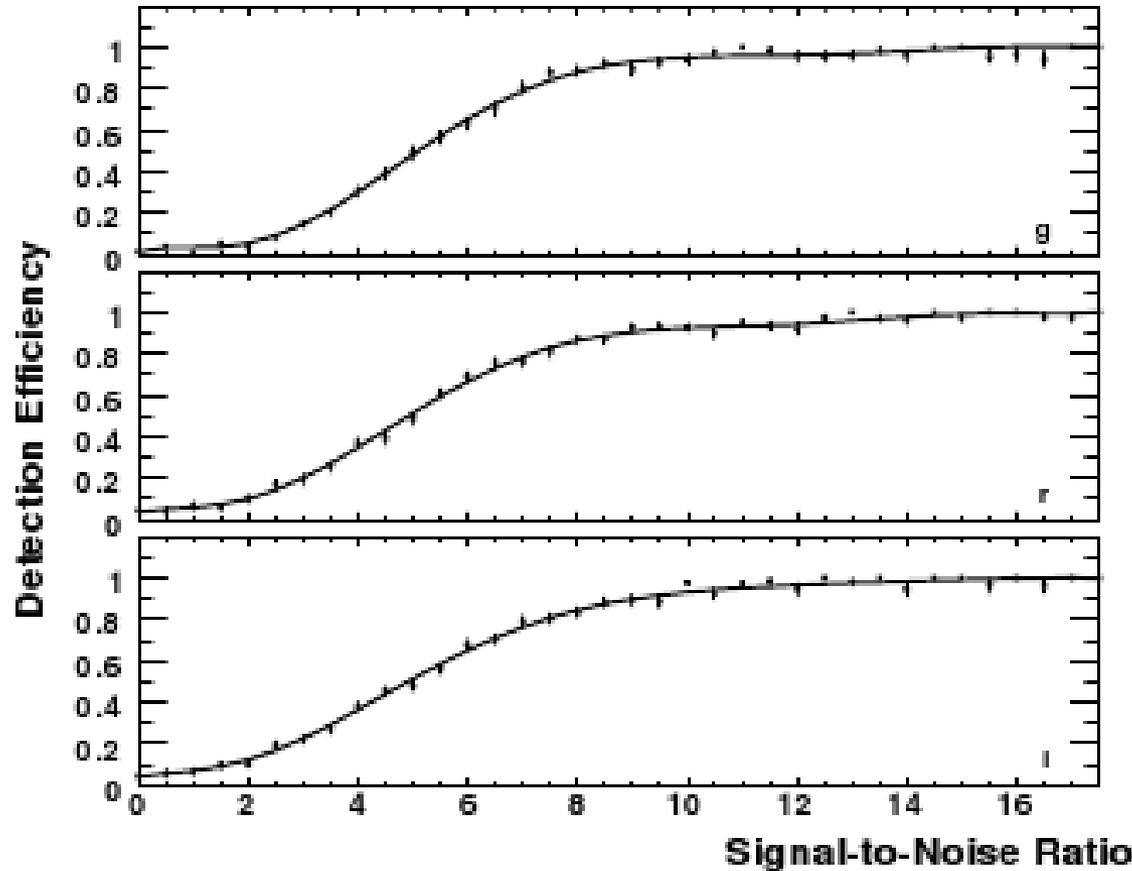
# DES vs. SNLS (rough estimate)

	SNLS	DES	Units
# Fields	4	2.5	~6 months/year
FoV	1	3	sq deg
Imaging total	1380	750	hr
Photometric?	75-80	50	%
Spectroscopy	1500	?	hr

Table courtesy of John Marriner



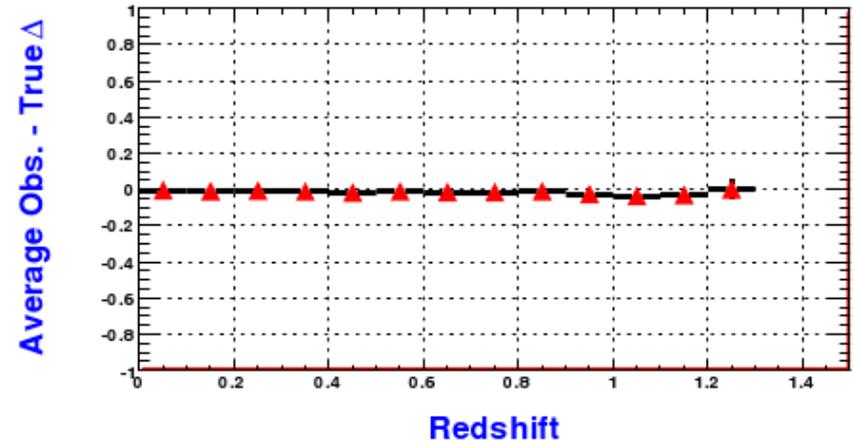
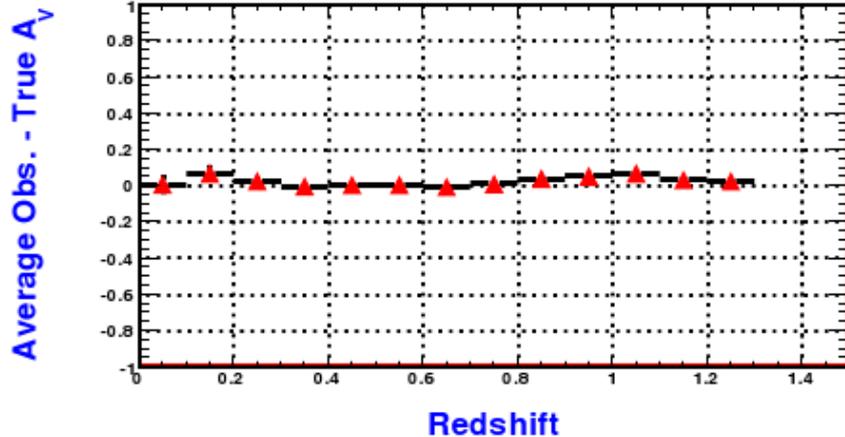
# Survey Efficiency for SDSS (software only)



Dilday, et al., arXiv:0801.3297v2 (2008; accepted by ApJ)

# No Bias in $A_V$ or $\Delta$

Deep (grizY): cuts of 1 filter  $> 10$  and any 3  $> 5$  S/N have been applied



# DETF Figure of Merit

Method	$\sigma(\Omega_{DE})$	$\sigma(w_0)$	$\sigma(w_a)$	$z_p$	$\sigma(w_p)$	$[\sigma(w_a)\sigma(w_p)]^{-1}$
BAO	0.010	0.097	0.408	0.29	0.034	72.8
Clusters	0.006	0.083	0.287	0.38	0.023	152.4
Weak Lensing	0.007	0.077	0.252	0.40	0.025	155.8
Supernovae	0.008	0.094	0.401	0.29	0.023	107.5
Combined DES	0.004	0.061	0.217	0.37	0.018	263.7
DETF Stage II Combined	0.012	0.112	0.498	0.27	0.035	57.9

Table 1: 68% CL marginalized forecast errorbars for the 4 DES probes on the dark energy density and equation of state parameters, in each case including Planck priors *and* the DETF Stage II constraints. The last column is the DETF FoM.  $z_p$  is the pivot redshift. Stage II constraints used here agree with those in the DETF report to better than 10%.